it may appear to be necessary to protect the pilot from sound or other conditions during a storm. Where the pilot has a fear of lightning, it is possible that tests or checks might be devised which would remove this fear.

Anything which will permit the safe landing of the plane or provide automatic control while the pilot is stunned would do much to eliminate the hazard that now exists. Owing to the increased reliability of aircraft, less attention will be paid to storms. While this will tend to increase the lightning hazard, it would seem that the present hazards can be more than offset by careful attention to the various factors tending to produce reliability.

OBSERVATIONS FROM AIRPLANES OF CLOUD AND FOG CONDITIONS ALONG THE SOUTHERN CALIFORNIA COAST

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While serving as aerological officer of the aircraft squadron, Battle Fleet, at the fleet air base, San Diego, Calif., during the summers and autumns of 1928 and 1929, many previously formed ideas of the California weather underwent a considerable change. Perhaps the most interesting of these was that, in so far as aerological officers and aviators are concerned, the weather lacks much of the regularity which had been expected from the claims of the Californians and descriptions of tourists. It is true that over the land adjacent to the ocean there is little rain during the summer, few thunderstorms and gales, and that the sky generally becomes cloudy during the night with clouds that burn off early the next morning, leaving the day more or less cloudless. (At sea the clouds may, or may not burn off, a fact of little concern to those on land but often vitally important to the aviator and navigator.) With this the regularity ceases, for the velo [1] clouds frequently form over land as early as 2 or 3 p. m., and continue until early morning, mid forenoon, or even until noon, at heights which vary from 1,000 to 4,000 feet, according to conditions. If the clouds form at an altitude of 2,000 feet or more, they are of little moment to the pilots of aircraft. However, when they develop at such an altitude that their bases are less than 1,000 feet, there is a considerable likelihood that they will continue to lower until they reach the surface, when, to all practical purposes, a dense fog results.

Since the flight operations are often delayed, cut short, and even rendered impossible by a velo cloud that fails to burn off at the usual time, or that forms earlier than the regular time, the aerological officer receives many inquiries from squadron commanders asking the time the sky will clear, the time that the clouds will form at night, what the ceiling will be, whether night flying is advisable, if the clouds will clear at sea during the day, and many similar questions. Obviously the answers to these questions are not always apparent.

During the summers of 1928 and 1929 many schemes were adopted in an effort to find the why and the wherefore of the southern California coast weather in the belief that if they were found, the when could be more easily determined. The current weather maps were available but did not explain many of the observed details. Old maps were studied in an attempt to classify them in accordance with certain very definite types of weather which were observed, but with little success. A study of the actual changes in the weather during these types proved to be more fruitful of results and accounted for many of the successful forecasts; but at times a very definite type would change suddenly, apparently without cause, and a more or less complete failure in the forecast would result. The lack of reports from the south and west made the identification of fronts difficult, and even impossible, much of the time. Further, meteorological literature was searched for a satisfactory explanation of presence of the velo cloud during the night and its absence during the day, at least over land. The explanations found did not appear to be of great practical value in forecasting the cloud conditions.

There remained, however, the aerograph records which had been made during the many aerological flights at the naval air station, and the opinion was soon formed that if an understanding of the velo cloud, and its many changes, were to be gained it would be from the visual observations and instrumental records obtained during flight. As stated, there were many records available, but these did not seem to give the detailed information desired. Practically all records made during the summer and autumn months showed that a temperature inversion existed over the air station during these seasons, and other records showed that the inversion was frequently present during the other seasons. This, of course, was already well known, as were the several theories which had been advanced to explain the cause of this condition, such as the Imperial Valley air theory and the settling air, or subsidence, theory. (The former states that the warm, dry air above the base of the temperature inversion [2] is air which has moved westward over the mountains from the Imperial Valley to the coast, while the latter explains the temperature and dryness of the upper air as due to the presence of the HIGH in the upper atmosphere over the semi-permanent thermal LOW at the surface in Lower California. The slow descent of air from this HIGH is given as the cause for the heat and dryness aloft.) The main points noted in the old records were that the temperature of the air decreased *rapidly* with the altitude until the base of the inversion was reached, then the temperature increased with continued increase in elevation to some definite point above which a more or less normal decrease in temperature occurred. The record showed that as a general condition the relative humidity increased from the surface to the base above which it decreased rapidly, usually to 50 per cent, or less; often to between 50 and 25 per cent; again, to less than 25 per cent; and occasionally to almost 0 per cent. However, it was found from observations during some of the aerological flights that there were inaccuracies in the temperature and relative humidity traces on the older records and also on the ones being made during the early summer of 1928. The inaccuracies in the relative humidity traces were caused by the type of humidity element installed on the aerograph, a type much too sluggish to record details during a routine climb. The temperature inaccuracies referred to were caused by the frequent delays in take off when the sun was shining. Experience showed that unless especial precaution were taken under these conditions a temperature of 2° to 5° C. above the true air temperature would be recorded at the time of the

[1] Velo cloud, the name given by Californians to the high fog or stratus cloud that drifts over land and generally burns off as the day advances.—*Editor.*

[2] For the sake of brevity the word "base" alone will be used on subsequent pages, the meaning in all cases being the same as in the present instance.

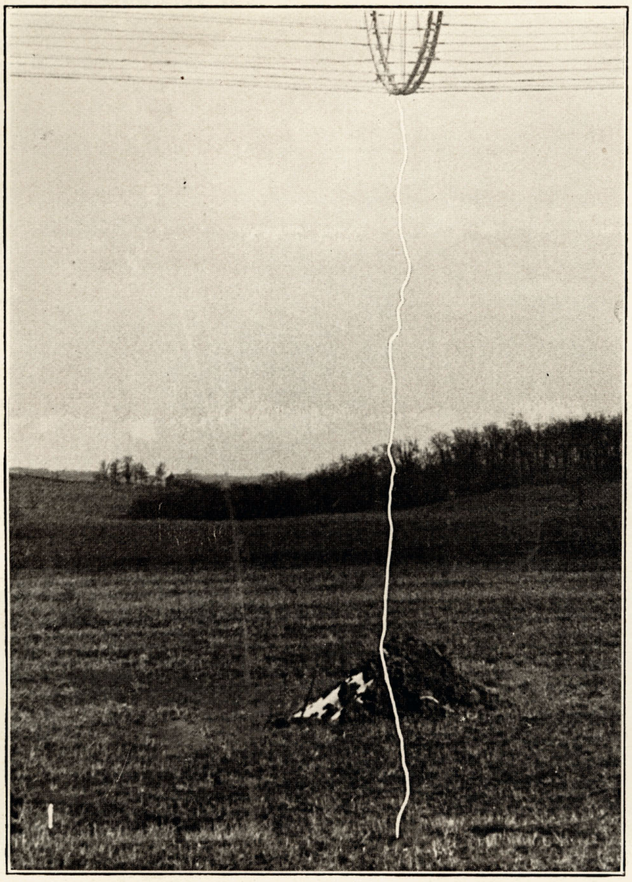

FIGURE 1.—Discharge from large condenser to ground at the high voltage laboratory of the Ohio Insulator Co. Photograph taken by synchronized camera

FIGURE 4.—Basket equipped with Van Orman cage for protection against lightning

FIGURE 2.—Showing the basket used on the *City of Cleveland* balloon which was struck while the balloon was at least 5,000 feet in the air

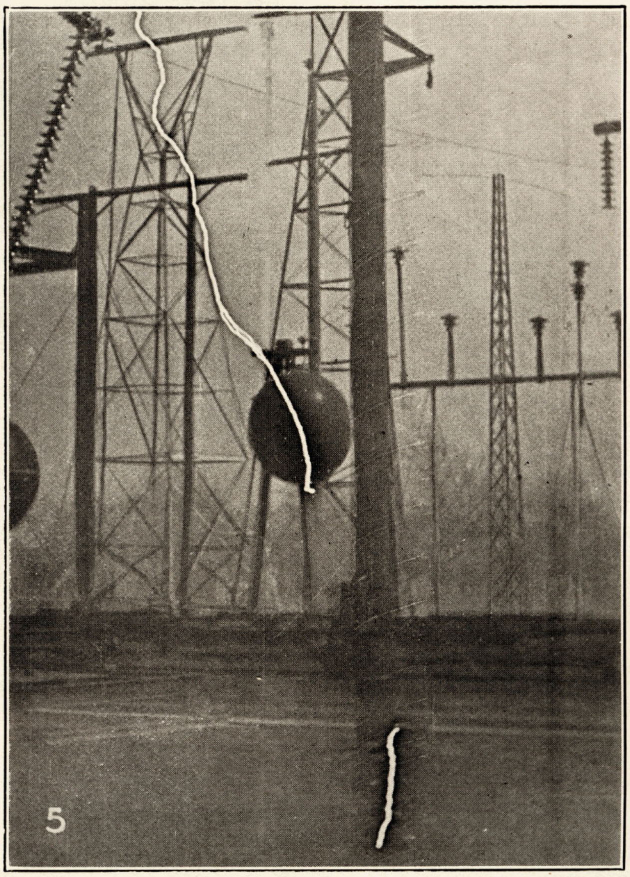

FIGURE 5.—Dry-hydrogen balloon with antennæ attached, subjected to lightning discharge without damage to balloon

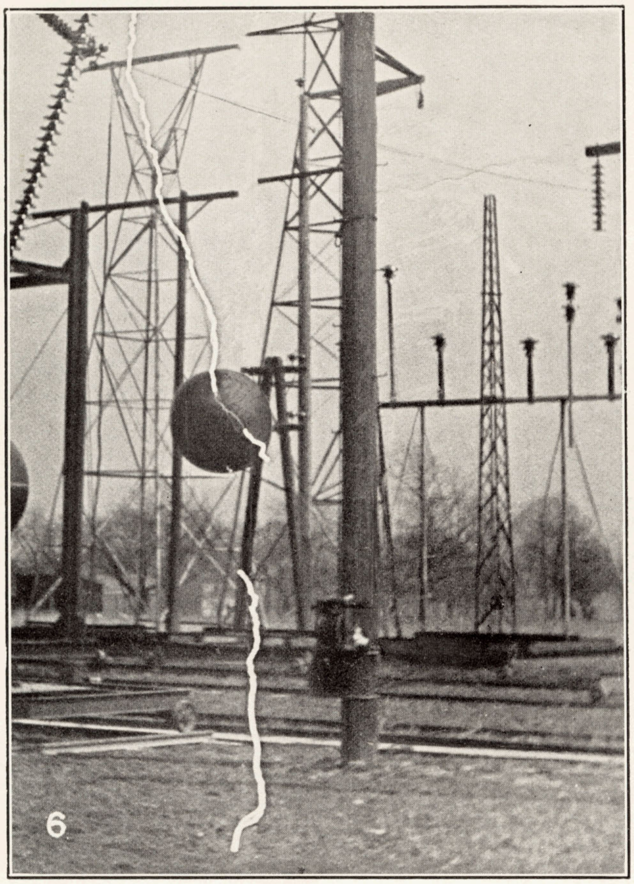

Figure 6.—Photograph shows discharge to the wet balloon causing its destruction

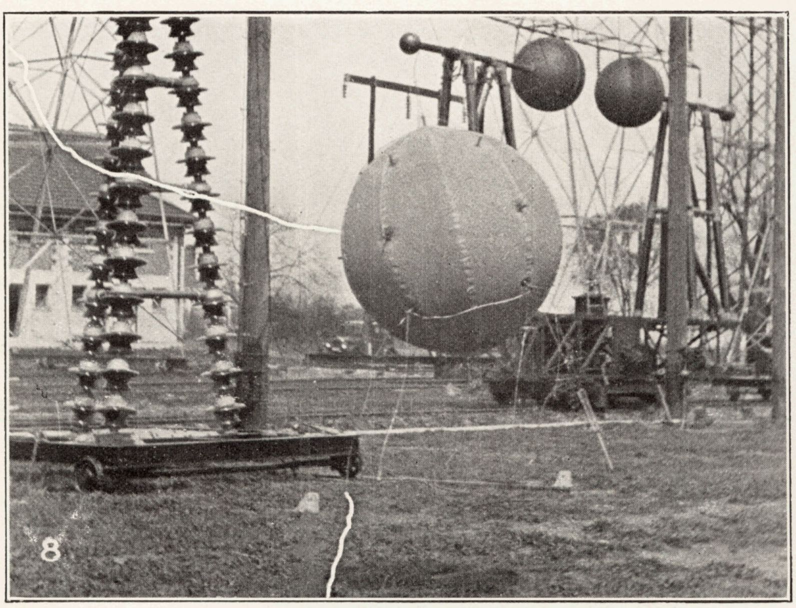

Figure 7.—Discharge taking place to one side of dry balloon equipped with cage and lightning rods

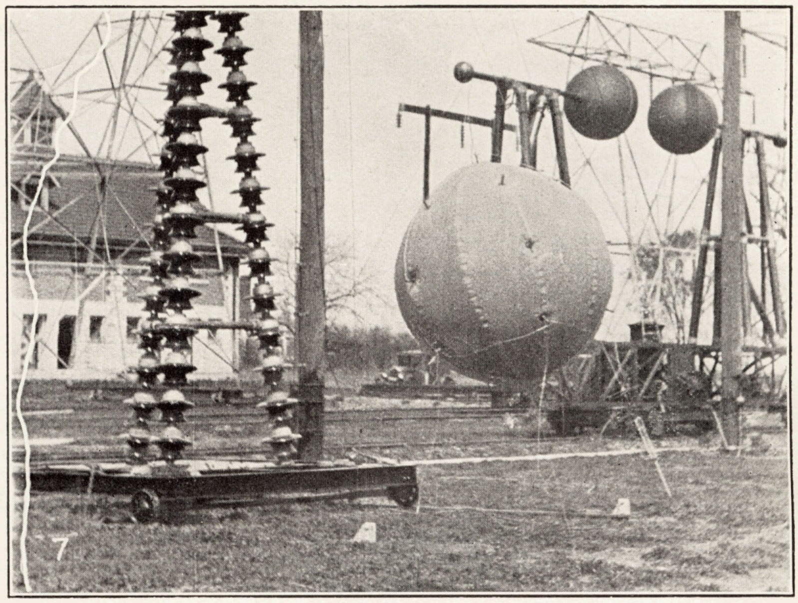

Figure 8.—The field set up by the wet balloon attracted the discharge which terminated on lightning rod raised from surface

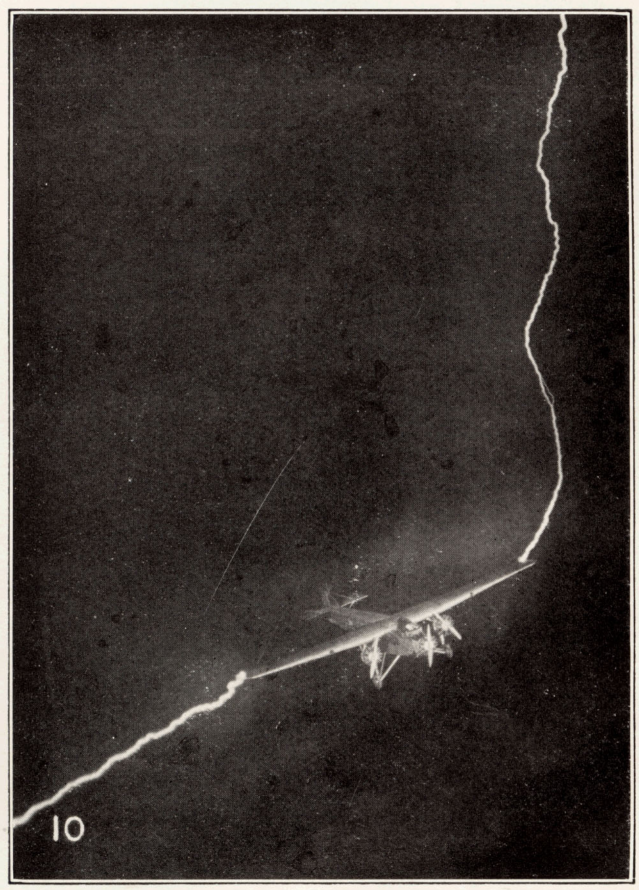

Figure 10.—Discharge entering and leaving from wing tip

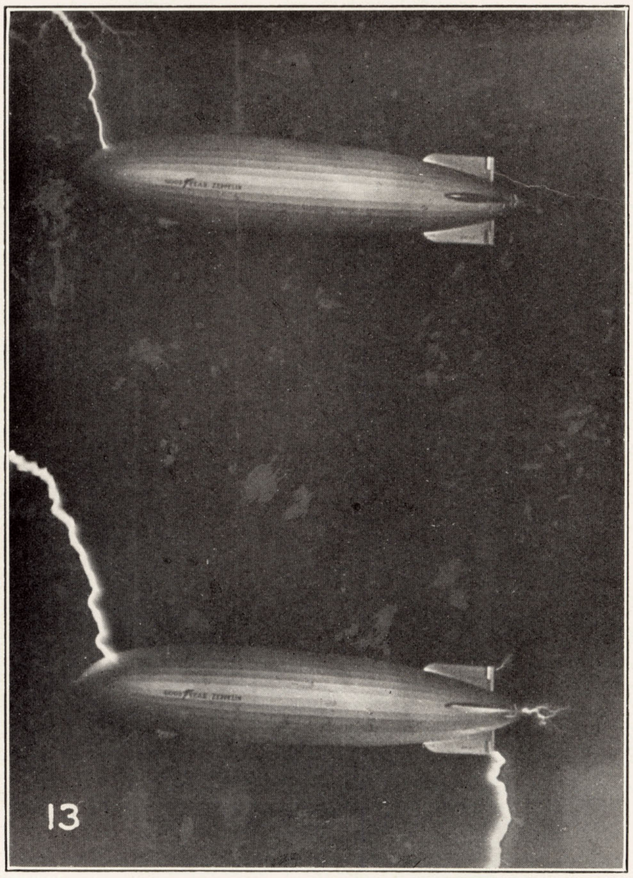

FIGURE 13.—Upper view: Discharge of limited capacity striking model Zeppelin. Lower view: Heavy discharge striking Zeppelin and continuing to ground

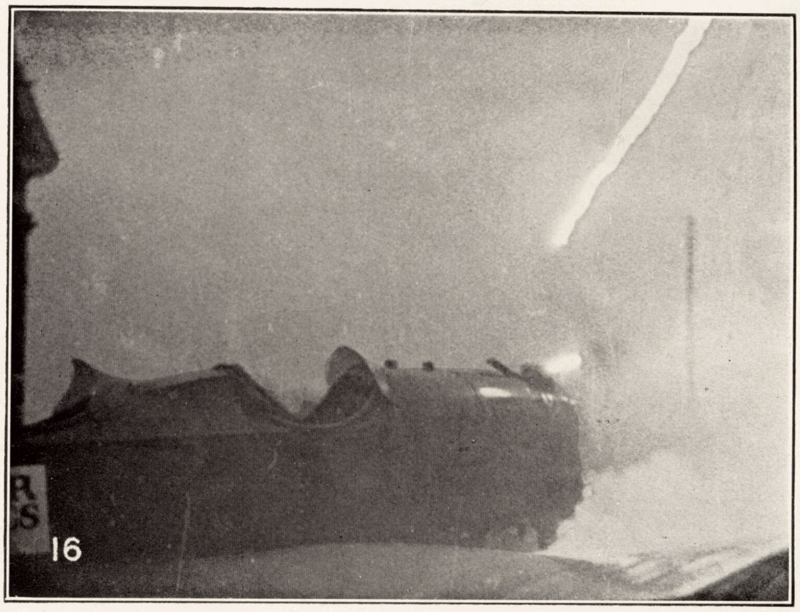

FIGURE 16.—Discharge to propeller while in operation. Discharge strikes from termination of metal on propeller to ignition system opposite

beginning of the flight and would, therefore, show a much too rapid fall in temperature from the surface to the base. The relative humidity records were greatly improved by the installation of new hairs in the aerograph, and the temperatures at take off were corrected for the naval air station by the introduction of certain modifications in the routine flights by Lieut. A. L. Danis, United States Navy, shortly after he reported for duty as aerological officer. Correct surface temperatures were more easily obtained by the aircraft squadrons' personnel since the flights were made from the water in a seaplane.

During 1928 routine aerological flights were being made daily, except Sundays and holidays, by the naval air station personnel, but because of the pressure of other duties only a limited number were made by the aircraft squadron's aerologist. During these flights, however, the opinion was soon formed that although the routine flights were of great value from the standpoint of information in general, they were not entirely suited to a study of this kind. This was due to the following causes: (1) being routine, they were scheduled for about the same hour each day; (2) the rate of climb, which was about 300 feet per minute, was too rapid for the recording of many details; (3) the length of the flight was usually quite limited owing to the fact that the data had to be worked up as soon as possible for use in the morning forecast and forwarding to the Weather Bureau, and also because of other operations scheduled for the plane.

During the summer and fall of 1929 it became possible to make many aerograph flights, not of a routine nature, to investigate special features of the local weather. Data gained from these flights, together with information received through conversation with officers who had cruised in various parts of the eastern Pacific Ocean, ship reports, and information obtained in the Weather Bureau office at San Francisco, led to a survey of the prevailing conditions along the coast and the adjacent ocean, and a study of their relation to the inversion and cloud conditions. This survey has shown that the inversion is normally a sea condition and exists over the land only in areas where surface air from the ocean has penetrated; that it is influenced at times by air from the Imperial Valley, or other inland districts, which is evident from the fact that pilot balloon records and observations of upper clouds and forest fire smoke show definite easterly winds aloft on many days; that much of the time inland air is not present, and therefore not necessary, because at times both surface and upper winds are from the sea for periods of several days. It is further quite evident that although the inversion does greatly influence the fog and velo cloud conditions, it is not the cause of either.

It was known that the inversion extended continuously along the coast from San Diego to San Francisco, and for a considerable distance to sea. It was also known to cover the land areas west of the Coastal Range and to exist over San Francisco Bay. During this survey it was learned that it extends north along the coast to the southern part of the State of Washington during the summer and, according to the best information available, extends 200 to 300 miles to sea. Numerous aerograph flights were made to points 30 to 40 miles west of San Diego, and also to the south, and the inversion was found to exist on all such occasions. On these flights, from altitudes of 8,000 to 12,000 feet, the characteristic clouds and haze could be seen to distances of more than 100 miles at sea, indicating that the inversion extended at least 100 miles or more to the west, southwest, and south. In February, 1929, the U. S. S. *Saratoga*, while en route from San Diego to Panama, experienced inversion weather well south along the California Peninsula. An aerograph flight 800 miles south of San Diego revealed a well formed inversion, and velo clouds covered the sky for another 200 miles. In June of the same year, while returning from Panama, the *Saratoga* passed under the characteristic velo cloud at about the same point off Lower California and continued under the same inversion conditions during the remainder of the trip to San Diego.

From all information obtained it seems safe to assume that during the summer the inversion ordinarily extends from southern Washington to a point 800 to 1,000 miles south of San Diego, west from the coast for a distance of 200 to 300 miles, and over the land areas between the ocean and the Coastal Range. This gives an area about 2,000 miles parallel to the coast, and about 250 to 350 miles west of the Coastal Range. Finding it difficult to explain an inversion over such an area, and with such different wind conditions, by the explanations given in the fourth paragraph (i. e., heated air from the inland and a settling of air from a HIGH in upper atmosphere) a more satisfactory explanation was sought. Upon consulting pilot charts it was found that the prevailing winds along the coast are from the northwest, covering a belt from Washington to Lower California, and about 200 to 300 miles to sea. Just to the west of the northwesterly wind belt there is a similar area with the prevailing winds from the north, and to the west of this, or beginning about 500 to 700 miles off the coast, the northeast trade winds are found and they continue to and beyond Hawaii. The characteristic weather of the northwesterly wind area is of the inversion type, and that of the trade winds in summer is of the instability shower type. What the characteristic weather is within the northerly wind belt was not determined. It was further found that the temperature of the water along the coast from Washington to Lower California is colder than that at a distance offshore, and that the water temperatures west of the San Diego-San Pedro area continue to rise to and beyond Hawaii. As would be expected, the temperatures fall to the north from San Diego and rise to the south, but the temperature changes along the coast, north and south, are not as great as the rise in an equal distance to sea, especially to the west and southwest. According to the Hydrographic Office Publication No. 84, Mexican and Central American Pilot, the warmest water of the eastern Pacific is found in the region 1,000 to 1,500 miles south and southwest of San Diego where the mean temperature in August is said to rise to 85 F.°, at times. The temperature of the sea water in the San Diego area at the same season is about 60° to 62°F. When it is remembered that during this same season the inversion is best developed, this fact becomes important.

The pressure gradients over southern California and the adjacent ocean are ordinarily very weak, especially in the summer, and the average surface winds correspondingly light. However, during the heated part of the day the sea breeze frequently attains a velocity of 12 to 18 knots, at least during the early part of the afternoon. It has been reported from observations taken on board some of our battleships while cruising west of San Clemente Island, which is about 60 miles offshore, that the winds in that district are frequently stronger than those nearer land. The reports referred to stated that the winds experienced were 18 to 25 knots, whereas a check showed that the winds along the shore on the days indicated were 10 to 15 knots. Ordinarily the winds aloft are likewise moderate, but occasionally very high velocities occur.

As stated above, the prevailing direction of the surface wind along the eastern edge of the Pacific is northwesterly. Probably it would be more accurate to state that along the immediate coast the prevailing winds are from the northwest to west. Easterly surface winds seldom occur during the summer except under Santa Ana wind conditions.[3] Prevailing directions at 500 to 1,500 meters are also northwest, but above that height the prevailing direction is southwest. These statements have been made after examining a table published in an article, "Temperature Inversions at San Diego, as Deduced from Aerological Observations by Airplane," by Mr. Dean Blake, of the Weather Bureau office at San Diego in the MONTHLY WEATHER REVIEW, June, 1928. The conclusions drawn from this table by Mr. Blake are as follows:

> Even the most cursory examination forces us to draw several obvious conclusions, namely: (*a*) That at virtually every level, winds were from the ocean the larger percentage of the time; (*b*) that between 2,000 and 10,000 meters the percentages from the land and ocean remain fairly constant; (*c*) that beyond 10,000 meters the few soundings obtainable showed an increasing frequency from the ocean; (*d*) that the prevailing direction at all levels was southwest; (*e*) that the northwest currents believed to predominate at the higher levels, summer as well as winter, were not in evidence.

It is not understood how Mr. Blake derived the conclusion marked "(*d*)" for the table, based on pilot-balloon soundings for June, July, and August during the years 1924 to 1927, inclusive, as the naval air station, San Diego, clearly shows the preponderance of northwest and west winds at the surface, and northwest winds at 500 to 1,500 meters. Aside from this, the conclusions appear to be sound. Regarding the velocities of the winds, Mr. Blake states:

> Although a chart has not been prepared for the velocities during the same period, it was further observed that at the soundings under 2,500 meters they were rarely other than light, and when from the eastern, or land, quarter were more in the nature of a drift than a current.

These conclusions are believed to have been substantiated during the summers of 1928 and 1929, except at the times of Santa Ana winds when very high velocities were sometimes found.

Continuing in this article, Mr. Blake states:

> If we can make our deductions from four years' record, then there must be other causes for the steep inverted gradients besides an overflow of hot air to the coast from convectional action in the Imperial and Colorado Valleys, as inversions occurred at every observation regardless of wind direction.

It is believed that sufficient facts have now been presented to show this "other cause." It will be remembered that practically all of the air over the coastal region comes from the sea. Except immediately along the coast to the north, the water everywhere, within a distance of 1,000 miles, is warmer than at any given point along California. This means that air from any portion of the Pacific Ocean, while approaching the coast, must pass over colder and colder water, and especially is this true when the air moves from the south or southwest where the temperatures rise quite rapidly with distance offshore. The processes which takes place as warm air passes over the colder water are relatively simple. The first effect is the cooling of the surface air to the temperature of the water. Due to friction between the air and the water, especially where waves have formed, the lower layers of air become turbulent and are filled with eddy currents which mix the cooled air with the warmer air above it, each mass leaving the surface tending to cool adiabatically as it rises. At first the surface air is thrown upward into warmer and less dense air and considerable energy is required. This energy is furnished by the wind. After the process has continued for some time the temperature of the air in this stratum decreases rapidly with altitude, in time equaling the dry adiabatic lapse rate. Above this stratum the temperature increases for a greater or lesser distance, and then decreases at approximately the original rate. After the dry adiabatic lapse rate has been established near the surface it will not require as much energy to throw a mass of air from the surface to a given distance aloft as at the beginning, hence, assuming the same wind velocity, surface air will be thrown to a greater height. There is a limiting distance, however, for each wind velocity which will vary somewhat with conditions of temperature and humidity.

Although statements were made above showing the prevailing wind directions for the various areas along the coast, it is not to be assumed that such winds are constant. For instance, the table of Mr. Blake, which was prepared from the afternoon pilot balloon records and therefore show the conditions at that time of day, shows that the surface winds were from the northwest on about 40 per cent of the occasions, from the west about 30 per cent, and from the southwest about 25 per cent. This shows that it is perfectly possible for air to approach San Diego from any portion of the eastern Pacific. Should a mass of air with a normal lapse rate of 3° F. per 1,000 feet move from the very warm area to the south and southwest, where its surface temperature was 80° F., it would reach San Diego with a surface temperature of about 60° F. If clouds have not developed, its lapse rate from the surface to the base, assumed to be 1,500 feet, would be approximately equal to the dry adiabatic, and the temperature at the base would be about 8° F. lower than at the surface, or about 52° F. The temperature of the air above this point would increase from the minimum of 52° F. to some point, say 1,000 feet higher, where a maximum temperature would be found which, in this case, would be approximately 72° F. This mass of air would, therefore, reach the coast with a 20° inversion, and the maximum temperature at 2,500 feet would be 12° F. higher than that of the surface air just off the coast. This maximum temperature would also be at least as high as that of the surface air at the fleet air base, or San Diego, on the normal day. By following a mass of air from any other point of the eastern Pacific, except almost directly along the coast to the north, it will be seen that it will reach San Diego, or any other point on the California coast, with an inversion but, of course, less in amount as the source of the air is farther to the north. Many degrees of inversion have been recorded by the aerographs, ranging from no inversion to one of 29° F., also with maximum temperatures aloft less than the surface temperature, equal to it, and greater. While this thermal stratification of the lower atmosphere is being established, important humidity changes occur. Once the inversion is formed, the water vapor, both the original and that received from evaporation, is distributed in the stratum below the base by the turbulence, and in this way the moisture content of the lower stratum is increased, while above the base the amount of water vapor remains about the same as it was originally. The surface turbulence causes the relative humidity to increase rapidly from the surface to the base. This, with con-

[3] Santa Ana wind or simply Santa Ana—A name given by Californians to a strong dessicating wind having a northerly component which under favorable pressure conditions blows through passes in the Santa Ana Mountains of southern California.

tinued evaporation, ultimately causes the dew point to be reached, following which clouds begin to form. Clouds and fog do not necessarily form early in this journey to the coast, both because the original air often does not have an especially high relative humidity, and also because the air does not come into contact with much colder water suddenly, as it does over the Grand Banks, in the Atlantic.

From what has been said above it appears that any mass of air approaching any point on the Pacific coast south of the State of Washington from a considerable distance at sea, except almost directly along the coast to the north, must develop an inversion very similar in characteristics to those observed day after day in the San Diego area.

Although both the surface and upper winds carry air from the sea to the land by far the greater percentage of time, still on some occasions there is a definite air flow from the land. A well formed Santa Ana wind represents the maximum development of such conditions. Santa Ana winds are caused by high pressure areas over the Central Plateau region with relatively low pressure off lower California. Such a pressure distribution causes air to flow from well inland to the coast as northeast winds. In approaching the coast the air descends from the plateaus and mountains to the sea level and is heated both adiabatically and by the highly heated valleys over which it passes. At times the winds at the surface reach, or exceed, gale force, while very high velocities frequently occur aloft. This air reaches the coast very hot and dry, and with considerably less density than that adjacent to the surface of the ocean, so it is forced to rise from the surface soon after passing the coast line. An exceptionally good illustration of this occurred during the summer of 1929 when a Santa Ana of more than usual intensity caused northeast surface winds with gusts exceeding 35 miles per hour at North Island, and caused such heavy clouds of dust that flying was discontinued during the afternoon. During this time the U. S. S. *Aroostook* was conducting exercises at sea, about 10 to 15 miles southwest of the naval air station. At no time did the *Aroostook* encounter northeasterly winds, but was in light westerly winds during the whole afternoon. The Santa Ana winds continued the next day but with considerably less velocity, no gusts exceeding 30 miles per hour having been recorded. At the time of these maximum gusts a large bombing and torpedo plane (*T4M*) took off to calibrate altimeters at 6,000 feet. The pilot gained the desired altitude at a point about 4 to 6 miles southwest of North Island and, upon signal, leveled off, but instead of remaining at 6,000 feet the plane continued to ascend to 6,900 feet regardless of the fact that the pilot was attempting to stop the rise. Before reaching the maximum altitude the pilot turned to the observer and indicated his inability to maintain the desired level. Although the cause for the strong ascending currents was not fully recognized at the time, another attempt was made farther at sea and the proper altitude was maintained for five minutes without difficulty. No reports were received from the surface craft on that day, but it seems safe to assume that the northeast winds did not remain at the surface for a greater distance than 4 or 5 miles after crossing the shore line. Through conversation with aviators and officers of the Battle Fleet, other instances have been learned of where vessels have experienced normal conditions within 15 to 20 miles of the shore at times when strong Santa Ana winds were reported at near-by ports. However, that the strong northeast winds frequently proceed hundreds of miles to sea in the upper levels is proved by reports of dust clouds and sand storms by ships several hundred miles at sea.

During the summer of 1929 aerograph flights were made both during and immediately following several Santa Ana winds. As would be expected it was found that the temperatures, both at the surface and aloft, were much above normal, and that the relative humidity, very low at the surface, approached 0 per cent aloft. As soon as the intensity of the Santa Ana decreased sufficiently to allow the sea breeze to be reestablished over the coast it was found that the characteristics of the stratum below the base had changed little, if any, from the normal, but aloft the high temperatures and very low humidities continued for several days.

The above paragraphs show the principal characteristics of inland and ocean air approaching the coast, that from land being hotter and much drier than that from sea. Just as Santa Ana winds are of rare occasion, so are winds of the solid current type from sea, for, as stated above, the pressure gradients are generally very weak over that portion of the sea during the summer. A special chart was prepared to study the inversion conditions on which all pilot-balloon soundings made at the naval air station during the latter part of the summer of 1929 were entered by means of arrows, flying with the wind, at the various altitudes. Red arrows represented easterly or land winds, and blue represented winds from the ocean. A study of this chart gave the impression that at times the air along the coast line frequently drifts inland for a day or two and then drifts to sea, or vice versa. This chart was not started until late in the investigation, and owing to other duties there was no opportunity to study it as fully as desired. The most interesting features noticed were that with a slow drift from land the upper air temperatures rose and relative humidity fell, while in apparently the same air drifting back from sea a day or two later the temperatures had fallen and the relative humidity had risen somewhat.

The main points brought out in the foregoing paragraphs are as follows:

(*a*) By far the greater portion of air reaching the California coast both at the surface and aloft, comes from the ocean.

(*b*) Air reaching the California coast from practically any part of the Pacific Ocean will have developed an inversion by the time the coast is reached. This air will have a considerable amount of moisture in the warm air above the base.

(*c*) When air flows over the coast and adjacent ocean from well inland it causes a larger inversion than is caused by air from the sea, and the amount of moisture above the base is very small.

(*d*) The upper air over the coastal waters and adjacent land is ordinarily a mixture of air from various areas, sometimes a mixture of inland and ocean air, but more often a mixture of air from various regions over the ocean. The inversions which occur under these conditions have characteristics intermediate between those of (*b*) and (*c*).

Velo clouds form in the moist stratum of air below the base as a result of processes to be described in a later paragraph. If the temperature of the surface air is considerably above that of the water toward which it is moving, or if it is highly humid before the cold water is reached, low clouds, or fog, will form far at sea and move landward with the air mass. This is especially true in the case of air from the south and southwest. On the other hand, if the temperature of the air approaching the colder water is only slightly higher than that of the water along the coast, or if its vapor content is relatively small, it may reach the coast with a well-developed inversion without either clouds or fog. However, if this air continues in contact with the ocean for any considerable length of time clouds will ultimately develop, because evaporation constantly adds water vapor to the lower stratum, and turbulence distributes it. It was stated that the turbulence in the lower atmosphere causes the cooling of air below the base and that this cooling might, in time, cause clouds. Solar radiation, however, opposes this and is the controlling influence most of the time during the day. A much more effective cause for cloud formation is found at night when radiation from the top portion of the moist stratum causes the already cold air just below the base to become colder. This, ultimately, results in instability, and any further cooling will cause convection. Obviously, these processes are operative throughout the night and the dew point will ultimately be reached. This accounts for the fact that the velo cloud forms only during the latter part of the afternoon or at night, and burns off during the next day.

Velo clouds always develop in the lower stratum where evaporation, turbulence, and convection are operative. So far as has been learned there always is an inversion above the cloud sheet; there certainly was on all occasions when observations were made in 1928 and 1929. Although these clouds are not formed by an inversion, but by the conditions in the stratum below the inversion, it does have a marked influence on them after they are formed. The height of the base is, in many cases, the determining factor as to whether the condensation will result in clouds or fog. The rate of increase in temperature above the base, and the amount of water vapor present, determine whether or not the altitude of the base will remain the same, or whether it will rise after condensation begins. This has a very definite influence on the height of the cloud sheet, its thickness, and whether or not it will develop downward to the surface. It is this lifting of the base through convection and condensation that causes a new mass of air from the south or southwest to so often produce fog at first and later only velo cloud.

It is believed that the "more satisfactory" explanation of the inversion, sought in an earlier paragraph, has been found, namely, that the inversion is a sea condition and is caused by the cold water along the coast. It explains why the inversion extends so far to the north and south and such a short distance east and west. It explains also why the inversion exists with deep westerly winds as well as winds from shore, and under pressure conditions which almost positively preclude the subsidence theory. Accepting the theory that the velo cloud is caused by thermal convections opens the way to understand some of the peculiar habits of the inversion and the base. It also explains some of the most interesting types of the irregular weather and, it is believed, it puts a very useful instrument into the hands of the forecaster who is compelled to answer the whens, the whys, and the how much.

The following paragraphs deal more directly with the observations made at San Diego during 1929, telling how the flights were made, what special conditions were observed, and how certain observations tend to substantiate the foregoing explanations regarding the inversion and the velo cloud.

Practically all of the flights were made in a seaplane, or an amphibian plane, over the ocean, and the air explored with a standard Friez aerograph attached to the outer portion of the right wing. During the period of these flights, aerological flights with the same type of aerograph were being made at the naval air station, San Diego, in a landplane which generally flew inland. At times it was arranged so that special flights were made to sea and inland simultaneously, and the records compared. Always on such flights the planes made one or more descents to cut the inversion at various places. At first considerable difficulty was encountered with the relative humidity element on the aerograph carried by the seaplane, and the records could be accepted only in a general way. Later new hairs were installed and thereafter the readings were considered as trustworthy as those on similar instruments.

Great effort was made to obtain correct readings on all flights. It had been noticed that the temperature traces on the records were frequently inaccurate at the take-off, owing to solar radiation, exhaust engine gases, etc. These records had led to the belief that the lapse rate from the surface to the base often greatly exceeded the dry adiabatic lapse rate, but flights made according to the adopted plan of having the correct temperature of the surface air before the take-off, and then rising very slowly, practically never showed a superadiabatic lapse rate, except for very limited distances. However, the true lapse rate was ordinarily found to equal, or closely approximate, the dry adiabatic. Close observations of the relative humidity pen during flight led to the belief that many of the older humidity records were erroneous, due to the rate of climb and the lag of the humidity element, and showed a rate of fall in the relative humidity above the base greatly in excess of the actual decrease. By rising very slowly and leveling off frequently, it was found that while the relative humidity does fall rapidly it does not usually fall as rapidly as believed from the old records, except where the upper air has come from well inland. In addition to the specific instances given, much time was spent flying along the base, and in and around forming and dissipating clouds. Special conditions were watched for and, when found, flights were made according to the plan which seemed best suited to determine the actual conditions.

The inversion is known to have covered the San Diego-San Pedro area not only on the days of these special flights, but on practically every other day during the summers and autumns of 1928 and 1929.

Careful observations, and aerograph records, during many flights showed that the top of the velo cloud almost always coincides with the base. When clouds are not present the base may be identified by the top of the moist surface stratum which, when viewed from above, has a milky appearance and is characterized by indifferent to very poor visibility near its top. Above the base the air is clear and the visibility good. The surface separating these air masses is so sharply defined a pilot may easily fly with the lower part of the plane in the moist stratum and the top part in the warm air above.

The inversion was identified on these special flights to points 30 to 40 miles south, southwest, west, and west-northwest of San Diego, and inland to the foothills and mountains, by means of the aerograph. On many of these days it was identified by means of the velo cloud and haze layer to points more than 100 miles to sea. The U. S. S. *Lexington*, en route from Honolulu to San Diego in June, 1928, passed under the velo cloud at a point about 200 miles off San Diego. This cloud sheet continued unbroken to the coast. The clouds were absent and the weather conditions entirely different at a point 360 miles offshore.

The top of the well formed velo cloud, and also of the haze layer, is remarkably level over the sea. Both are higher over land during the day, due partly to the contour of the country and partly, no doubt, to the thermal conditions. Little difference could be found in the height of the base a short distance offshore and 30 to 40 miles at sea, although great care was taken in these determinations since it was, and is, believed that the surface stratum is wedge shaped and that the inversion is much lower, and of considerably less magnitude, at a distance of 100 to 150 miles to the west. Several records definitely showed a smaller inversion 30 to 40 miles at sea than a few miles offshore, and a few were believed to show a lower altitude, but the difference was so small the records were not considered conclusive. The heights of the base were always obtained from records made during slow ascent, since it had been found early in this investigation that aerograph readings made during ascent should not be compared with those obtained on descent.

As was to have been expected, it was found that the amount and sharpness of the inversion was less over land than over sea during the day, and that both of these conditions decreased with distance inland.

Many flights were made to determine the lapse rate from the surface to the base in clear weather. On these flights the plane was allowed to remain on the water with the aerograph on the windward wing and in the shade of the upper wing until the temperature trace was steady. This was done to insure that the true air temperature was recorded at the take-off. To overcome instrumental lag, the ascent to the base was made very slowly, as much as 30 minutes having been required to climb 2,000 to 2,500 feet on several occasions. All records obtained during flights of this type show a lapse rate equal to, or closely approximating, the dry adiabatic lapse rate. In a few instances a superadiabatic lapse rate was found for short distances. These flights also showed a gradual increase in relative humidity from the surface to the base. Several theoretical humidity curves were prepared from the Neuhoff Chart for comparison with individual aerograph records. To obtain this curve the current surface humidity was taken and, assuming that the moisture had been thoroughly distributed by turbulence, points were picked off the chart in accordance with the temperatures found at the various altitudes. On some flights the relative humidity traces showed that the water vapor had not been thoroughly distributed, and in every instance the sky remained clear until late at night, although on several occasions clouds began forming in late afternoon, but soon dissipated.

The impression had been gained from many records that the relative humidity fell off very rapidly above the base. In nearly every case where the plane climbed very slowly into the inversion it was found that this falling off in relative humidity is considerably more gradual than had been anticipated, i. e., because of the sluggishness in the instruments, the lower strata above the base had been given credit with a degree of dryness which ordinarily does not exist. This, of course, is what would have been expected had it been known that the velo cloud is caused by convection.

The velo cloud occurs at sea far more frequently than over land, or even along the coast. Observations from planes have shown that, toward the end of a period of clear weather, clouds form far at sea, at least 50 to 100 miles, and spread eastward. It is not unusual to observe a well formed sheet, or bank, of velo cloud far beyond San Clemente Island, 60 miles distant, a day or two before clouds form over, or near, the shore. During normal summer weather, when the days are clear and the nights cloudy, the clouds begin forming over the sea several hours before any develop over land. On many of the brightest days on shore a cloud bank covers the ocean from a point a few miles offshore to a distance of more than 100 miles.

The first indication of the formation of the velo cloud is the appearance of innumerable cloudlets in the topmost part of the moist stratum. When viewed from above these cloudlets resemble little puffballs. They increase rapidly in number and size, merging with one and another, until large globular masses of clouds are formed. These clouds also increase in size and finally merge to form the velo cloud sheet. Observations of the above conditions have been made repeatedly from planes flying along the base. When watched from this level it is seen that the formation of the cloudlets is preceded by the appearance of little lumps on the top of the moist stratum, or haze layer, which, up to this time, has been remarkably smooth and level. In a short time small cloudlets can be seen forming in the lumps and as the plane flies along the base a marked increase in bumpiness can be noticed as it passes through that area. After the cloudlets have grown into the globular masses of clouds, mentioned above, well defined ascending currents can be noticed when flying through them.

The above observations, of course, suggest convection. Although the thermal conditions have been shown to be favorable for convection during late afternoon and night, a more positive confirmation of the idea is found from the fact that, in nearly all of the cases observed, the base rose over the forming clouds, i. e., the cold, moist air rose into the warm air above. This could easily be observed from the milky appearance of the moist air as well as by the clouds themselves. Under certain favorable conditions, namely, when the temperature increased but slowly with altitude above the base, and there was a fair amount of moisture in the warm air, the base was found to be 300 feet higher over a mass of forming clouds than in the surrounding clear areas. Under similar conditions the top of a well formed sheet of velo cloud was observed to rise 300 feet in 5 minutes and another 200 feet during the next 15 or 20 minutes. This observation was made in the late afternoon when the bank was approaching the shore. The base sloped downward from the top of the clouds, which were more than 1,200 feet in depth, to the original base along the coast. Clouds were developing rapidly under the sloping portion of the base, being in the form of small puffballs near the shore, globular masses a little farther at sea, and columns near the edge of the bank.

Some aerograph records show a very rapid rise in temperature and a very rapid decrease in relative humidity above the base. The Neuhoff Chart shows that the base can not rise to any extent under these conditions even though the cloud sheet attains considerable thickness. Since radiation from the top of the moist layer must continue, whether the base rises or remains the same, the convection will continue and, instead of the top of the clouds becoming higher, the base of the sheet will become lower. Many flights have shown the height of the base in the morning to be approximately the same as during the preceding afternoon, and it is not uncommon to observe a very low cloud base in the early morning. There is a peculiar fog condition which occasionally results from the lowering of the cloud base. This condition has been carefully watched in San Diego where the base of the clouds could be seen to become lower until it obscured the tops of the high buildings, then the lower buildings, and finally rested on the surface and appeared in all respects like true fog. As this occurred at night it was possible to see the base of the cloud as it approached the street lights, and it was observed to be very irregular and ill-defined. Such fogs generally do not last more than two or three hours. When they clear they sometimes do so from the bottom up and again from the top down, i. e., in the former the cloud clears at the surface but continues aloft, while in the latter the top either clears, or descends, until the surface is reached and the sky remains clear the remainder of the night. The latter condition was observed more frequently than the former. If a sharp base is known to be at 1,000 or 1,200 feet, or less, and the relative humidity at the surface somewhat above normal, fog is to be expected that night.

It hardly seems necessary to mention that the presence of a considerable amount of high clouds, either cirro or alto clouds, greatly retards the forming and burning off of the velo cloud. However, this is a fact and must be considered by the forecaster when attempting to answer some of the whens he is asked.

The flights and observations described above were made largely because of the belief that if the inversion and the velo cloud were more fully understood, the explanation of the various types of weather would follow. Although it was impossible to verify many of the following contentions, it is believed that the principles set forth in the preceding paragraphs satisfactorily explain many of the perplexing questions which confront the forecaster along the California coast. Among the most important of these may be mentioned (*a*) the existence of the inversion with deep westerly winds as well as with winds from land; (*b*) why the velo cloud forms; (*c*) why it is typically a night cloud; (*d*) why it occurs over the ocean so much more frequently than over the land; (*e*) why it frequently does not burn off at sea; (*f*) why the base frequently rises during the night; (*g*) why the cloudiness sometimes increases for several days and then decreases during the next several days (occasionally the clouds will disappear entirely within 24 to 48 hours and the resulting clear weather will continue for several days); (*h*) why fog is almost sure to develop along the coast and for several miles inland on nights when the base is less than 1,200 feet high, especially when the temperature above the base increases rapidly; (*i*) why this type of fog clears over the land within a few hours, sometimes from the ground up, but more often "from the top down"; and why a light mist sometimes falls in the early morning during the summer.

It is recognized that the observations made in 1929 are but the beginning of those necessary to solve the riddle of the irregularities of California's regular weather, but it is felt that useful, as well as interesting, information has been obtained. It is seen that the aerograph has become much more helpful to the forecaster because, by means of it, he is supplied with such very useful information, as, the height of the base, the amount and sharpness of the inversion, the humidity above the base, and the lapse rate and distribution of moisture below the base. All of these data are of practical value in forecasting local weather and, in all probability, will become more so as additional facts are learned since, even with the imperfect ideas held during this investigation, the thickness of the morning velo cloud and the height of the base were forecast several times from the afternoon aerograph record and the Neuhoff chart. It is granted that this was largely the result of chance, since the assumptions made were only guesses. Still there appear to be no good reasons why, with additional knowledge, not only the height and thickness of the clouds and the height of the base, but also the other features which are of vital importance to the aviator and navigator will be forecast with confidence and accuracy.

SOUTHERN ARIZONA FLYING WEATHER

By LEON C. WALTON

[Weather Bureau Office, Phoenix, Ariz.]

Science and invention have accomplished considerable in recent years to further the cause of aviation. Equipment has been improved and many valuable lessons learned, often at great cost, so that aerial navigation has been stripped of most of its perils. In flying circles, the weather remains a favorite topic but even that has been shorn of its terror, not because we can defy or control the elements, but due to the excellent system of reporting and forecasting conditions as they are and as they will be a few hours or days hence.

No section of the country enjoys "perfect" weather, but southern Arizona is probably as free from weather hazards as is any locality in the United States.

The route selected by the Southern Transcontinental Airline from El Paso, Tex., via Douglas, Tucson, and Phoenix, Ariz., to Los Angeles, Calif., traverses a flat open terrain, with the exception of a low range of mountains near the Arizona-New Mexico boundary, and a scattering of hills, some of which have been dignified by the name of "mountain." Throughout the greater portion of the year, a pilot flying over this territory at an altitude exceeding 1,500 feet is in a realm where the visibility is limited only by the power of his own eye. Haze, smoke, fog, low clouds, and other limiting agents are of such rare occurrence as to be almost negligible. Snow, sleet, and ice are practically unknown, and the only place they could occur would be in the upper reaches over the only range of mountains crossed.

Dense fog, so feared in many localities, seldom obscures the Arizona landscape. It has been observed only 36 times in the past twenty years at the Phoenix Weather Bureau office, and the distribution by months leaves most of the year fog free. December leads with 20; January follows with 11; November supplies 4; and March furnishes the other day with dense fog. Five of the twenty years have had none at all. During the winter months an occasional blanket of smoke partially obscures the city of Phoenix but leaves the airport clear. At Douglas, Ariz., the smoke occasionally cuts the visibility to as little as 3 miles, but is never dense enough to offer a serious handicap to flying, as the "blanket" is not more than 300 or 400 feet in thickness.

Another indication of the excellent visibility is the fact that the beacons between Phoenix and Los Angeles are located about 30 miles apart. East of Phoenix the airway is not yet lighted but when installation is completed the average distance between beacons from Dallas to Los Angeles will be as nearly uniform as possible.

Ceilings are usually unlimited, or at least, sufficient to allow a generous margin of safety. In time of precipi-